constant $n$. In the formula as given in the paper referred to the coefficients $C$ and the exponents $h$ are functions of the temperature. The stress $P$ is constant and $\rho$ is approximately one-half.

[4] It was found by experiment that for stresses not too great, the "direct" curve (on applying the stress) and the "return" curve (on releasing) were the same; or rather if the former is $S$ and the latter $R$, then $S - R = Ct$.

# NOTE ON THE SIMPLE DEVICE FOR INCREASING A PHOTOGRAPHIC POWER OF LARGE TELESCOPES

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Among the many problems in sidereal astronomy that demand great telescopic power the three following may be cited as particularly significant for inquiries relating to the origin and evolution of stellar and galactic systems: (1) The total number of stars and limiting faintest magnitude in globular clusters; (2) the frequency and distribution of dwarf stars in clusters and in the sky at large; (3) the limits of the galactic system in certain directions. To these stellar problems we should add the highly interesting questions connected with the faint extra-galactic nebulae, and note that important contributions toward their solution seem to be only a little beyond our present telescopic power. Thus the best available photographs of globular clusters suggest that we are approaching the faintest magnitudes, and that, if we could only extend our studies two or three magnitudes farther, one phase of the problem of dwarf stars could probably be solved.

The longest exposures with the 60-inch reflector have yielded apparent photographic magnitudes between 20 and 21. The Hooker telescope, it is believed, will gain about a magnitude over the 60-inch provided the focal images are not much larger; but in the case of nebulae, since the ratio of focal length to aperture is the same for the two reflectors, no gain is to be expected except in scale, which is of course important for revealing new structure and purposes of measurement, but will not bring fainter structure to view. Small nuclei will also be shown in stronger contrast with the 100 inch telescope.

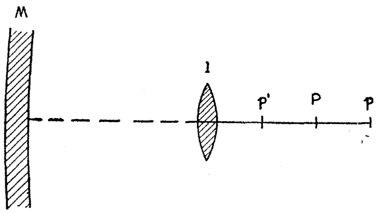
The investigation of faint stars and nebulae is of sufficient importance to justify every attempt to increase beyond normal limits the working range of great reflectors. Since these instruments are universally adapted to photographic observation, the problem is one of increasing the brightness of the image or increasing the sensitivity of the photographic plate.

In the device described below the principle employed is to increase the brightness of the image by reducing its area. This is accomplished by placing a short focus lens in the converging beam at an appropriate distance in front of the photographic plate. The immediate result is to re-

duce the effective focal length of the telescope, thus giving high speed and reducing the scale on the photograph.

In studies where the important thing is scale, an intensifying lens does not help; further, if a large field is desired, the intensifiers now available are unsatisfactory. But for the problems mentioned above, where scale and field are of second importance to limiting magnitude, the intensifying device is efficiently and inexpensively adaptable.

For example, by using such a device at the primary focus of the 100-




inch, so as to reduce the scale to that of the 60-inch, the exposure time needed to give a required density in the photograph of a nebula should be less than one-half that otherwise necessary, even after allowing for a reasonable loss of light in the lens system of the intensifier.

Several lenses have been experimented with successfully in combination with various telescopes during the last six months. I am indebted to Mr. Benioff, who was associated with me in the early plans and experiments, for assistance in adapting the different intensifiers.

Let

$F_1$ be the focal length of the objective (mirror) of linear aperature $A$, $\overline{MP}$

$f$ be the focal length of the intensifier of linear aperture $a$, $\overline{Ip}$

$f'$ be the apparent focal length of the intensifier in the converging beam, $\overline{Ip'}$

$F$ be the equivalent focal length of the combination,

$d$ be the distance between the objective and intensifier, $\overline{MI}$

$D = F_1 - d$ be the distance from the focus of the objective to the intensifier, $\overline{IP}$

$R = F/F_1$ be the reduction of focal length and linear scale of the field.

From the relation giving the focal length of a combination of lenses we derive,

$$F = \frac{F_1 f}{F_1 + f - d} = \frac{F_1 f}{f + D}, \tag{1}$$

$$R = \frac{f}{f + D}. \tag{2}$$

Equation (2) shows that for a given intensifier the reduction depends only on the distance of the intensifying element from the normal focal point, $P$, of the telescope. Since the reduction is independent of the apertures and the focal length of the objective (mirror), being a function only

of the focal length of the intensifier and its position in the cone of light, a given intensifier will reduce the focal lengths of all telescopes in the same ratio when placed at a fixed distance in front of the normal focal plane. The one now in use at Mount Wilson is suitable without structural alteration for work at both the primary and secondary foci of the 60-inch and 100-inch reflectors, and with the 10-inch photographic refractor of 45 inches focus. Conditions analogous to those above hold for amplifying lenses.

An interesting corollary of equation (2) is that no advantage accrues from having an intensifier of large aperture, unless, for the sake of accommodating a larger field, the increase in size can be made without increasing its focal length. Difficulties would obviously arise if the focal length of the intensifier were so short or so long that the distance of this secondary lens from the normal focus interfered with the photographic operations. Cf. equation (4) below.

The distances $\overline{IP} = D$ and $\overline{p'P} = D - f'$ are important in the actual manipulation of an intensifier. In the formula for conjugate foci,

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v},$$

we may put $u = f'$, $v = -D$, so that

$$\frac{1}{f'} = \frac{1}{f} + \frac{1}{D}, \tag{3}$$

and from (2)

$$f' = RD, \quad D - f' = D(1 - R). \tag{4}$$

That is, for any desired reduction of the effective focal length, the distance of the modified focus from the ordinary focal plane of the telescope is $1 - R$ times the distance of the intensifier from that plane. Equations (2) and (4) define the arrangement of a given intensifier and the photographic plate.

As an illustration, let us suppose that in working with the 100-inch Hooker telescope the reduction desired is $R = 1/3$, and that the focal length of the intensifier employed is $f = 3$ inches; then $D = 6$ inches, $D - f' = 4$ inches. The primary focus of the Hooker reflector is $F_1 = 42.3$ feet. From (1) the equivalent focal length is 14.1 feet, and we have, in effect, a 100-inch reflector with a focal ratio of 1.7 instead of 5. If we assume that not more than 25% of the light is lost in the intensifier, the theoretical gain of the telescope (limiting faintness) is a little more than two magnitudes.

For $R = 1/2$ the same intensifier should give a gain over normal photographic power of approximately 1.25 magnitudes, and leaves the scale very slightly inferior to that of the 60-inch reflector.

The most efficient intensifier for use with telescopes built for usual photographic purposes will be one that is adaptable to a large range of values of $R$; it should probably have a focal length between two and five

inches and the largest aperture possible, and should not be wasteful of light through reflections from numerous glass-air surfaces. If an extended object, rather than a point source, is to be photographed, the flatness of the intensifier field is important; or, better still, its focal properties should be such as to improve the field of the primary.

Putting $S = F/A$ and $s = f/a$ for the ratios of focal length to aperture for the objective (mirror) and intensifier, respectively, we find the minimum equivalent focal length, which is obtained when the cone of light from a source on the axis exactly fills the intensifier, is

$$F_{\text{min}} = \frac{F_1}{1 + S/s};$$

also

$$D_{\text{max}} = Sa.$$

For the Mount Wilson reflectors $S = 5$, and the greatest reduction of scale, for full accommodation of the convergent light, is

$$R_{\text{min}} = \frac{1}{1 + 5/s}.$$

An intensifying lens with focal ratio 1.0 would, at the limit, increase the theoretical photographic limit by nearly four magnitudes for a source on the axis.

Intensifying devices are particularly suited to reflecting telescopes because of the freedom from chromatic aberrations; also they should be of especial value when used with instruments of largest aperture and longest focal length because in studies of faint nebulae the large scale allows the minification necessary for increased speed. Influences of bad seeing, or any other defects in the photographic images, are obviously minimized with the intensifier—a fact that may make it possible to use large reflectors under conditions otherwise impracticable.

The lens now in use is a Dallmeyer No. 2 Kinematograph of 3 inches focal length and focal ratio 1.9. It has a fine field, but the many glass-air reflections considerably diminish the light. The lens is mounted so that the reduction can be readily changed, with a range of $R$ between $^5/_7$ and $^2/_7$ at the primary focus of the 100-inch reflector. For $R = {}^1/_2$ the workable field is about 6′ in diameter—quite sufficient for most clusters and nebulae; for $R = {}^1/_3$ it is one third as large. A comparative discussion of results obtained will be made in a later communication. The preliminary observations, which include successive exposures on the same plate with and without the intensifier, show that, when a reasonable allowance is made for loss of light in the lens, the predicted results are fully obtained, at least for nebulae. For instance, a three minute photograph of the spiral Messier 77, with a reduction of $^3/_8$, shows much fainter nebulosity than a ten minute exposure without the intensifier; and in the star cluster Messier 3 a reduction of $^8/_{15}$ gives a gain of nearly a magnitude for exposures of equal length.